45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit
2 - 5 August 2009, Denver, Colorado

AIAA 2009-4877

# Aluminum-Ice (ALICE) Propellants for Hydrogen Generation and Propulsion

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**An experimental investigation was conducted to determine the relative propulsive performance and viability of novel solid propellants comprised of ALICE using fundamental techniques such as steady-state strand experiments and applied experimentation such as lab-scale static fire rocket tests. Burning rates, slag accumulation, thrust, and pressure are some of the experimental parameters obtained. System scaling has been performed to examine the effect of larger systems on slag accumulation and performance parameters. The effect of pressure on the linear burning rate was examined and correlated using a Saint Roberts's law fit. The pressure exponent for ALICE was 0.73, which is approximately a factor of two larger than Al/water mixtures. Three sizes rocket motors ranging from internal diameters of 0.75 to 3-in. Nozzle throat diameter and igniter strength were varied. It was found that ALICE propellants successfully ignited and combusted in each lab-scale rocket motor, generating thrust levels above 223 $lb_f$ for expansion ratios of 10 and center-perforated grain configurations (3-in length). For the 3-in motor, combustion efficiency was around 70%, while the specific impulse efficiency was 64%.**

## I. Introduction

ALUMINUM-water combustion has been studied since the 1960s[1,2,3,4,5] as a viable propellant for propulsion since the Al-$H_2O$ reaction liberates a large amount of energy during combustion as well as green exhaust products.[6,7,8,9,10] Currently, propellants used for Earth to orbit and orbit-to-orbit missions are expensive. Thus, there is quite a need for new-generation propellants which can be used in the booster stage as well as possess characteristics which make them storable in Low Earth Orbit (LEO). Storable propellants in LEO will also be required for lengthy periods of time, which imposes greater constraints on cryogenic hydrogen. Inexpensive Al-$H_2O$ propellant systems for space exploration have been the subject of scientists and researchers for several years. The simplicity of Al-$H_2O$ propellants makes them favorable as in-situ propellants for lunar and Mars missions. Retaining the combustion product on board may also be considered if reduction methods are available to regenerate the aluminum fuel during the mission. The idea of designing inexpensive propulsion systems to launch payloads into LEO allows for relaxed requirements for launch such as lower success rates. Aluminum and liquid water research studies have slowly transitioned into aluminum and other fuels combusting with refrigerated or "frozen" oxidizers.

Lo *et al.* examined frozen hydrogen peroxide with polyethylene (PE) or hydroxyl-terminated polybutadiene (HTPB) solid propellants for solid rocket booster or lower stages.[11] Their composition is referred to as Cryogenic Solid Propellants (CSP). It has been postulated that these "green" propellants could be employed as early as 2010. They studied the burning behavior of CSPs in a 1-kg sandwich (disk stack) configuration in a pressurized

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